CARDIAC IMAGING AND NON-INVASIVE TESTING

Use of automatic exposure control in multislice computed tomography of the coronaries: comparison of 16-slice and 64-slice scanner data with conventional coronary angiography

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Heart 2007;**93**:1040–1043. doi: 10.1136/hrt.2006.103838

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Accepted 16 January 2007
Published Online First 29 March 2007

Objective: To evaluate the radiation-dose-reduction potential of automatic exposure control (AEC) in 16-slice and 64-slice multislice computed tomography (MSCT) of the coronary arteries (computed tomography angiography, CTA) in patients. The rapid growth in MSCT CTA emphasises the necessity of adjusting technique factors to reduce radiation dose exposure.
Design: A retrospective data analysis was performed for 154 patients who had undergone MSCT CTA. Group 1 (n = 56) had undergone 16-slice MSCT without AEC, and group 2 (n = 51), with AEC. In group 1, invasive coronary angiography (ICA) had been performed in addition. Group 3 (n = 47) had been examined using a 64-slice scanner (with AEC, without ECG-triggered tube current modulation).
Results: In group 1, the mean (SD) effective dose (ED) for MSCT CTA was 9.76 (1.84) mSv and for ICA it was 2.6 (1.27) mSv. In group 2, the mean ED for MSCT CTA was 5.83 (1.73) mSv, which signifies a 42.8% dose reduction for CTA by the use of AEC. In comparison to ICA, MSCT CTA without AEC shows a 3.8-fold increase in radiation dose, and the radiation dose of CTA with AEC was increased by a factor of 1.9. In group 3, the mean ED for MSCT CTA was 13.58 (2.80) mSV.
Conclusions: This is the first study to show the significant dose-reduction potential (42.8%) of AEC in MSCT CTA in patients. This relatively new technique can be used to optimise the radiation dose levels in MSCT CTA.

Rapid advances in multislice computed tomography (MSCT) imaging technology have substantially improved the diagnostic accuracy of non-invasive coronary artery imaging, leading to increasing numbers of MSCT computed tomography angiography (CTA) investigations. The increasing relevance of this investigation in clinical routine emphasises the necessity of looking into radiation dose exposure. To attain a radiation dose as low as reasonably achievable a new technique providing an automatic exposure control (AEC) and tube current modulation has recently been introduced to most state-of-the-art MSCT equipment. The aim of this study is to evaluate the dose-reduction potential of this new technique for MSCT CTA.

METHODS

Principles of modulation systems

There are two methods of reducing radiation dose exposure in MSCT CTA: ECG-triggered tube current modulation (ECG-TTCM) and AEC, an automatic tube current modulation technique. ECG-TTCM provides an online modulation of tube current. In every cardiac cycle, the tube current is raised to the nominal level during a limited interval in the diastolic phase.[1] This technique was introduced in MSCT equipment several years ago and resulted in a 34%–42% dose reduction in phantom measurements.[1]

In general, the cross section of the human body differs significantly from a circular shape. Hence, for different MSCT view angles, the *x* ray path length and, therefore, the attenuation of the *x* ray beam vary significantly.[2] The new online tube current modulation system for MSCT takes this fact into account by automatically adjusting tube current in the x, y plane (angular modulation) or along the scanning direction (z-axis modulation) or both (combined modulation) according to the size and attenuation of the body region being scanned to obtain constant image quality using a lower radiation dose.[2–7] Different vendors offer various techniques of AEC.[2] In this study, the CARE Dose 4D technique (Siemens, Medical Solutions, Erlangen, Germany) was applied. This technique includes combined angular and z-axis modulation.[2] The tube current modulation is based on attenuation information obtained from the localiser scan. Furthermore, the adaptation of tube current is performed on the basis of the mAs quality reference, which indicates the mean effective mAs used for a reference patient (typical adult weighting 70–80 kg).[2] In the diagnostic scans (CTA, calcium score scan (CaSc)), tube current modulation is then performed for each slice position (z-axis modulation) and for different projection angles within each *x* ray tube rotation (angular modulation).[2–4]

Patients and scan protocols

A retrospective data analysis was performed for 154 (116 men, 38 women) patients who had undergone MSCT with different MSCT scanners and different protocols. All patients had suspected or known coronary artery disease and were investigated for clinical reasons and indications. Written informed consent was obtained for all investigations.

In group 1 (39 men, 17 women; 65.96 (7.81) years old; heart rate (HR) 64.07 (11.35) bpm; body surface area (BSA) 1.96

Abbreviations: AEC, automatic exposure control; BSA, body surface area; CaSc, calciumscore scan; CTA, computed tomography angiography; DLP, dose–length product; ECG-TTCM, ECG-triggered tube current modulation; ED, effective dose; HR, heart rate; ICA, invasive coronary angiography; MSCT, multislice computed tomography

Table 1 Scanning protocols for multislice computed tomography in patients with suspected or known coronary artery disease

	Group 1		Group 2		Group 3	
Protocols	**CaSc**	**CTA**	**CaSc**	**CTA**	**CaSc**	**CTA**
Tube voltage	120 kV	120 kV	120 kV	120 kV	120 kV	120 kV
Effective mAs	133 mAs	550 mAs	150 mAs	550 mAs	190 mAs	850 mAs
Rotation time	0.375 s	0.375 s	0.375 s	0.375 s	0.330 s	0.330 s
Collimation	16×1.5	16×0.75	16×1.5	16×0.75	64×0.6	64×0.6
AEC	−	−	+	+	+	+
ECG-TTCM	+	+	+	+	−	−

+, with application of this technique; −, without the application of this technique; AEC, automatic exposure control; CaSc, calciumscore scan; CTA, computed tomography angiography; ECG-TTCM, ECG-triggered tube current modulation.

(0.18) m^2), MSCT CTA was performed with a Sensation Cardiac 16-slice scanner (Siemens Medical Solutions, Forchheim, Germany) equipped with the STRATON tube (Siemens Medical Solutions), after a standard coronary protocol including premonitoring, monitoring, MSCT and CaSc. ECG-controlled tube current modulation techniques with retrospective ECG gating were used for all investigations. For investigations in group 1, AEC (CARE Dose 4 D) was not applied. All patients of group 1 underwent invasive coronary angiography (ICA) with a conventional angiographic system using automatic selection of *x* ray beam filtration. The investigation followed a standard protocol of eight projections (six left coronary artery, two right coronary artery with left anterior oblique, right anterior oblique, lateral and posterior–anterior projections). In group 2 (41 men, 10 women, 58.84 (10.68) years old, HR 60.94 (7.40) bpm, BSA 2.01 (0.16) m^2), MSCT CTA was carried out using the same 16-slice scanner. AEC was applied in addition to ECG current tube modulation. Group 3 (25 men, 22 women, 57.36 (10.23) years old, HR 55.00 (5.80) bpm, BSA 1.85 (0.18) m^2) was investigated with a Sensation Cardiac 64-slice scanner (Siemens Medical Solutions) using CARE Dose 4 D, but with no ECG current tube modulation. Table 1 lists the scanning protocols for the different groups.

Both ICA and MSCT were performed by experienced investigators.

Evaluation

Effective dose (ED) was chosen as the best parameter to assess and compare the radiation dose exposure. For ED calculation in MSCT, the dose–length product (DLP) was multiplied with a conversion factor k (units: mSVmGy·cm) specific for the region of the body being scanned (in this case, the chest, with a value of 0.017 $mSvmGy{\cdot}cm^{-1}$) [8–11]:

$$ED = k \times DLP$$

The DLP incorporates the total scan volume and varies from patient to patient (eg, total scan length and scan width).[8 9 11] This generic estimation method was proposed by the European Working Group for the Guidelines on Quality Criteria in CT.[12] The values of ED predicted by DLP and the conversion factor k, as well as the values of ED estimated on the basis of sophisticated calculation methods as provided by different software packages, resulted in a maximum deviation of 10%–15% from the mean, thus presenting a reasonably consistent effective dose-calculation method.[8]

For ICA, effective doses were calculated by multiplying the dose–area product and a conversion factor k of 0.10 $mVGy^{-1}cm^{-2}$ for both men and women, according to the conversion factors published by Le Heron[13] for lateral and postero–anterior radiation exposures in the chest area.[10 14–16]

Statistical analysis

Values for ED are presented as mean (SD). Categorical data were given with absolute frequencies and percentages. A one-sample Kolmogorov–Smirnov test was used to test normal distribution of data (all variables (age, BSA, HR and all ED values) showed normal distribution). t Tests (normal distribution) were performed to evaluate the differences in patient radiation exposure. Values of $p<0.05$ were considered statistically significant. Statistical analysis was performed with the statistical software SPSS V.10.0.

RESULTS

MSCT and ICA were performed without any complications in all patients. Table 2 presents the ED values for CaSc and for CTA with and without CaSc for all groups.

Application of AEC (CARE Dose 4D) resulted in a 53.7% dose reduction in CaSc, a 42.8% reduction in CTA without CaSc and a 47.3% reduction for the combination of CaSc and CTA in group 2 versus group 1 (fig 1) p values = 0.000. The patient characteristics of groups 1 and 2 were comparable regarding BSA and HR—that is, factors possibly influencing radiation dose (no significant differences with p value for BSA 0.322 and 0.092 for HR). Hence, it is reasonable to compare the radiation doses of these two patient groups.

Comparing groups 2 and 3, there were significant differences regarding BSA (p = 0.000) and HR (p = 0.000), with higher BSA and HR in group 2. Both factors can cause higher radiation doses.[17 18] But even when this is taken into account, the radiation dose in group 3 was 2.4 times that in group 2 (absolute dose values in table 2), which is significant with a p value of 0.000.

To evaluate the possible influence of BSA on radiation dose and the dose-reduction potential of AEC, subgroup analyses for groups 1 and 2 were performed. Table 3 gives the results.

Since the mean BSA was 2.0 m^2, the patient groups were subdivided into slim patients, with BSA <1.90 m^2, and obese

Table 2 Effective doses (mSv; mean (SD)) values for the different groups*

	Group 1	Group 2	Group 3
CaSc	2.72 (0.35) (n1 = 45)	1.26 (0.28) (n2 = 36)	1.83 (0.50) (n3 = 36)
CTA	9.76 (1.84) (n1 = 56)	5.58 (1.41) (n2 = 51)	13.58 (2.80) (n3 = 47)
CTA with CaSc	12.46 (2.22) (n1 = 45)	6.57 (1.51) (n2 = 36)	15.37 (3.21) (n3 = 36)

CaSc, calcium score scan; CTA, multislice computed tomography of the coronaries.
For explanation of groups see table 1.

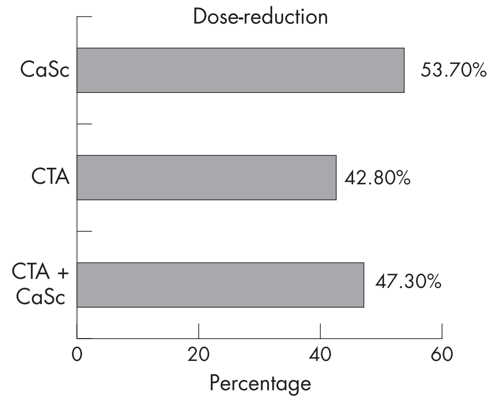

Figure 1 Dose reduction achieved by automatic exposure control in 16-slice multislice computed tomography (comparison of groups 1 and 2). CaSc, calcium score; CTA, computed tomography angiography.

patients, with BSA >2.10 m^2. The mean ED value of ICA (group 1) was 2.6 (1.27) mSv. In comparison, the ED in group 1 was 3.7 times higher, in group 2, 2.1 times higher and 5.2 times higher in group 3. In a subanalysis of group 1, sensitivity, specificity, and positive and negative predictive values for the detection of >50% diameter reduction were calculated using ICA as the standard of reference. On a per-segment basis, the overall sensitivity of CTA was 73%, specificity 98%, PPPV 71% and NPV 98%. Excluding the coronary segments with a diameter <2 mm, sensitivity was 81%, specificity 98%, PPV 75% and NPV 98%.

Table 3 Subanalysis regarding effects of body surface area on radiation dose (mSv) and dose reduction by automatic exposure control

	BSA <1.90	BSA >2.10	
	Mean (SD)	Mean (SD)	p Value
Group 1			
CaSc	2.63 (0.41) (n1 = 13)	2.75 (0.38) (n2 = 9)	0.508
CTA	9.77 (2.10) (n1 = 17)	11.08 (3.26) (n2 = 11)	0.206
CTA with CaSc	12.05 (1.86) (n1 = 13)	13.01 (3.16) (n2 = 8)	0.383
Group 2			
CaSc	1.17 (0.44) (n1 = 5)	1.36 (0.31) (n2 = 5)	0.560
CTA	5.80 (2.43) (n1 = 7)	6.99 (2.32) (n2 = 9)	0.338
CTA with CaSc	6.78 (2.59) (n1 = 5)	6.90 (1.63) (n2 = 5)	0.935

BSA, body surface area; CaSc, calcium score; CTA, computed tomography angiography.

DISCUSSION

This study is the first providing reliable patient data for radiation dose exposure in 16-slice and 64-slice MSCT CTA with the application of the recently introduced AEC technique. The results of this study show that AEC is a technical innovation that is able to significantly reduce radiation dose in MSCT CTA. The analysis showed a higher dose-reduction potential for CaSc (53.7%) than for CTA (42.8%; fig 1). In comparison, application of AEC in radiological scanning protocols of the chest resulted in a dose reduction by 20%–23.7% in patient measurements,[3,4] whereas in phantom measurements, the dose could be reduced by 66% for chest investigations.[1] These different results emphasise the need for separate evaluation of cardiac protocols in a clinical setting, as cardiac and radiological chest scanning protocols vary. Phantom measurements are necessary and very useful. However, they may differ greatly from real-life cardiac MSCT settings, because of fixed artificial heart rates, fixed scan lengths and a small number of different phantom volumes with a very regular shape instead of an irregular body shape.

Initial studies have shown that AEC techniques can increase the radiation dose for obese patients.[3] The data of this study did not show any statistically significant difference between the radiation doses of slim and obese patients, either with or without the application of AEC (table 3). There was a trend for higher radiation doses with higher BSA, but without any statistical significance.

Comparing the data from 16-slice and 64-slice MSCT, one should bear in mind that AEC was used in both scanning protocols, yet 64-slice MSCT CTA was carried out without using ECG-TTCM. Not using tube current modulation provides the advantage of maximum flexibility in reconstruction intervals, but it results in significantly increased effective doses for 16 and 64-slice scanners alike.[19,20] According to the results of Grees *et al*,[1] the radiation dose of 13.58 mSv in our data could have been reduced to 8.42–8.96 mSv by the application of ECG-TTCM. In any case, the data indicate that effective dose values are substantially higher in 64-slice MSCT than in 16-slice MSCT. This again emphasises the need for further dose-reduction techniques.

As expected, mean EDs used with MSCT CTA were higher than for ICA (9.76 mSv in group 1, 5.58 mSV in group 2 and 13.58 mSv in group 3 compared with 2.6 mSv in ICA of group 1). However, with the application of AEC in 16-slice MSCT, the mean effective dose for CTA is only 2.1 times higher than for ICA. With this in mind, CTA tends to become a real alternative to ICA, both for its improved diagnostic accuracy, with sensitivities/specificities ranging in the high 90s, and for its radiation dose.[19–25]

CaSc has its own diagnostic value, yielding different information from that gained with MSCT CTA or ICA.[26,27] It is associated with a lower ED than CTA, and even lower when AEC is used (table 2).

In comparison, nuclear diagnostic techniques are associated with even higher radiation dose exposures than MSCT. For combined rest and stress investigation using ^{99m}Tc-sestamibi, mean doses of 8.7 (1.7) mSv are used; for ^{201}Tl-chloride, mean doses amount to 22.1 (7.4) mSv (in another study, 17.3 mSv).[28,29]

STUDY LIMITATIONS

For ethical reasons, it seems inappropriate to perform a prospective study with the aim of an intraindividual comparison of radiation dose values in different scanning modalities. Unlike standard radiological MSCT examinations of chest, abdomen or pelvis,[3–6] there is—apart from a few individual exceptions—no justifying clinical indication to perform several MSCT CTA investigations in the same patient. Therefore, this retrospective data analysis was only able to compare different patient groups.

In this study, image quality was not evaluated systematically. However, all investigations provided sufficient image quality to evaluate all coronary segments in clinical routine. In radiological studies of the chest, abdomen and pelvis, MSCT image quality proved stable when AEC was used.[4,5] However, further studies focusing on this issue in MSCT CTA are required to evaluate whether this dose-reduction management affects diagnostic accuracy.

CONCLUSION

Cardiac MSCT with new dedicated scanners expose patients to a significant amount of radiation. Therefore, radiation dose optimisation is a highly important issue that must be addressed by both cardiologist/radiologist and manufacturers of MSCT scanners. AEC techniques are an exciting recent technological innovation contributing to radiation dose optimisation. The results of this study clearly underline the significant dose reduction potential of these techniques for MSCT CTA. The ongoing technical innovations improve image quality on the one hand and reduce radiation dose exposure on the other hand. However, the indication for MSCT CTA as an alternative to ICA is yet to be clearly defined.[30]

ACKNOWLEDGEMENTS

This study was supported by the Willy Robert Pitzer Foundation, Bad Nauheim, Germany.

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Competing interests: None.

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